New Trends in Microsurgery and Applied Technology

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Dr. Yasargil suggested to me that it might be good if I spent more time talking about coagulation than anything else, and since I am deeply interested in that and since it does not come up elsewhere in the program, I thought I would finish with a rather more detailed discussion of coagulation. An electrosurgical device with a spark generator was first brought into an operating room in 1910. It had a motor-driven rotating-disc as a static generator with a spark gap, a Leyden jar as a capacitor and a resonating coil. It put out a powerful discharge with which one could almost cook living tissue but which was not generally used. In 1928, W. T. Bovie, a physicist and one of the earliest biophysicists, developed an electrosurgical unit in which a spark gap generator provided an output of damped irregular waveforms of about a megahertz in frequency which permitted coagulation, and with a synchronous resonating circuit, also providing cutting ability. Cushing used this machine to revolutionize some of his removals in areas where bleeding had not been controllable before. Cushing's first publication began with a note by Bovie which is remarkably erudite now more than 65 years later.

Let me take a moment for basic principles. Direct current has a voltage level which stays constant through time. Alternating current on the other hand changes its direction with each side of the circuit changing from positive to negative, and the time it takes to do this is the frequency of the alternating current. Our ordinary power line current is either 50 or 60 cycles per second (Hertz). The amplitude up from the zero line is the voltage and this is the same as pressure in a hydraulic system. The current, which is measured in amperes, is a measure of how many electrons have passed through in a unit of time. The total power is the volts times the amperes but that applies only to direct current. The power line alternating current describes a sinusoidal wave form.

The amount of current that can flow at a given voltage depends upon the resistance of the material through which it flows. Resistance is a direct current term. Impedance is its equivalent for alternating current since other factors determine how alternating current can go through a material. Those are frequency and phase shift which I will not go into today because of time constraints. Constant current stimulators are the ones most frequently used for electrophysiology today. This is the diametric opposite of power distribution for our cities. If constant current were used, the current, whether one lamp or a million were turned on, would be the same. There would be no light from the million bulbs and the one bulb would disappear in a flash of smoke. With a constant voltage system, which is what is used, no matter how many bulbs you put in, no matter how many air conditioners run, since the voltage remains constant, all bulbs stay at the same brightness and appliances at the same level. For the coagulator nothing could be more important than constant voltage. In a constant current system, if you had saline over the field virtually nothing would be left for the coagulation at the tip since most of the current would flow through the saline, whereas in a constant voltage system, the closer the voltage is regulated. the lower will be the effect of the shunting of the saline and the more will the voltage and the power at the tip remain the same to go through the tissue.

The constant voltage is determined by the generator impedance. The lowest possible impedance in the generator gives you the best regulation of the voltage and the most constant voltage so that the current flowing is going to rise if the tissue impedance is low, and the voltage across the tissue will remain the same regardless of the impedance, regardless of the forceps area. Engineers will tell you that for transferring power, the generator impedance and the load impedance should match and that is perfectly true if your problem is the transfer of power with the highest efficiency. We are totally uninterested in efficiency. We have power to waste and what we want is for the power to be always available at the forcep tip. So the matching load idea in the system is for us totally without reason. Current must flow across at the tips of the forceps despite the fact that it is immersed in saline all the way, which requires a very low generator impedance as close as possible to a constant voltage system.

As Bovie pointed out, there is a difference between cutting and coagulating current. Cutting is performed with a constant sine wave, from a perfectly smooth resonant system. It also requires only a small tissue area to be involved. It is generally done with a fairly high voltage so that a tiny spark ahead of the electrode actually divides the tissue by molecular resonance. At one megahertz the macromolecules of

cuts. Coagulating is done with bursts of damped waves, and a somewhat larger tissu area for the amount of power.

The important factor is the arrhythmicity. A coagulating waveform is an ar rhythmic wave form where not 2 cycles are alike, where there can be no true reso nance i.e. no molecular resonance and the lowest division of tissue. The two require ments for coagulating are an arrhythmic waveform and damping, which means th voltage will come in bursts and each burst will go downward and then recur again sc that any resonance that takes place will be stopped between the bursts.

If you use a human and put an electrode on the brain and a ground plate on the back, the impedance between the two at about a megahertz is about 1500 ohms. The impedance between the tips of the bipolar forceps on the brain is about 80 ohms Now under those circumstances, if you look at the power required, you realize tha only 5% or so of the generator power is needed to coagulate the surface with the bipolar at that point on the brain than would be needed with the monopolar and ground plate.

When Greenwood first developed bipolar coagulation back in about 1939, he used it by putting one side of the forceps to each side of the Bovie machine and just disconnecting his ground plate so that he had a very high leakage from one side of his forceps to any ground on the patient. But if you look at it this way, the impedance between his forceps tips was 80 ohms, his impedance to ground at the best 1500 or so. Only 5% of the current was leaking away, i.e. 1/20th. So despite the fact that his system was totally without isolation, he only had a 5% leakage current and that isn't too bad and it did indeed work for him.

With the separate isolated bipolar unit, there is only the flow between the forcep tips and virtually none any other way, which does indeed prevent leakage current. If you use a unipolar forceps and just touch it with the Bovie, the best return path to ground is through the blood in the parent vessel and you may very well damage the parent vessel. With the bipolar, there is no flow into the parent vessel and, of course, you can seal just the branch you want, preserving the main trunk.

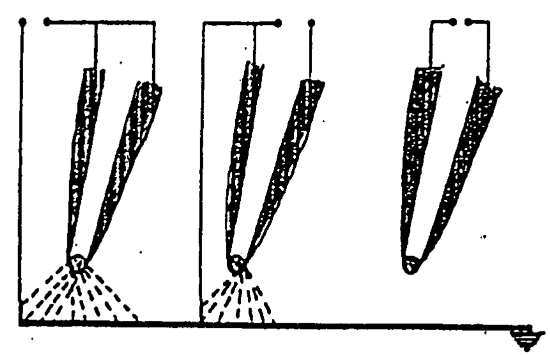

Fig. 14. On the *left* the unipolar coagulator. Current flows from the forceps to the dispersive electrode or ground plate. *Center section;* unisolated bipolar connection. Most of the current flows between the tips of the forceps but leakage current flows from the active electrode to the dispersive ground plate. On the *right* the isolated bipolar connection with the current flowing only between the

To summarize this, you have the Bovie unit with the unipolar unit going to ground, the bipolar unisolated unit as Greenwood used it with 5% leakage in the human, and finally, the true isolated bipolar unit with all the power going through the forceps tips and no leakage to going ground (Fig. 14). Now when you go to repeat this experiment in the rat, you get a very different most misleading result. There have been papers in the literature saying that based on rat studies the leakage of some of the commercial units is too great to be safe. When you use a Bovie unit on a rat, the impedance is 150 ohms, so half the current will go to the ground plate; if you use an unisolated generator with bipolar forceps instead of 1/20 of the current as in the human. So you must take the rat leakage current studies and divide them by 10 in order to have any meaning for the human. To put it simply, the leakage current in any commercial bipolar, no matter how badly built, is not high enough to be a problem, no matter which company has made it. Reducing leakage current is helpful in avoiding interference with monitoring equipment and television cameras.

The way to determine leakage and its damage – if you are really worried about it – is to put one forcep blade of the bipolar on the surface of the rat brain and turn the power all the way up keeping it on for a minute or so. Then inject the live animal with methylene blue and if it doesn't stain, there is no significant damage. It is not the measurement of current that is important, it is what happens to the brain.

Another comparison between bipolar and unipolar coagulation: one side of the brain is stroked with the unipolar at the lowest power setting that will coagulate all the surface vessels; the other side with the bipolar under the same circumstances and then the methylene blue injection is given. There is indeed damage going deep with the unipolar which is the result of heat spread, and there is superficial damage from the bipolar, essentially the result of destroying the cortical vascular supply, and the

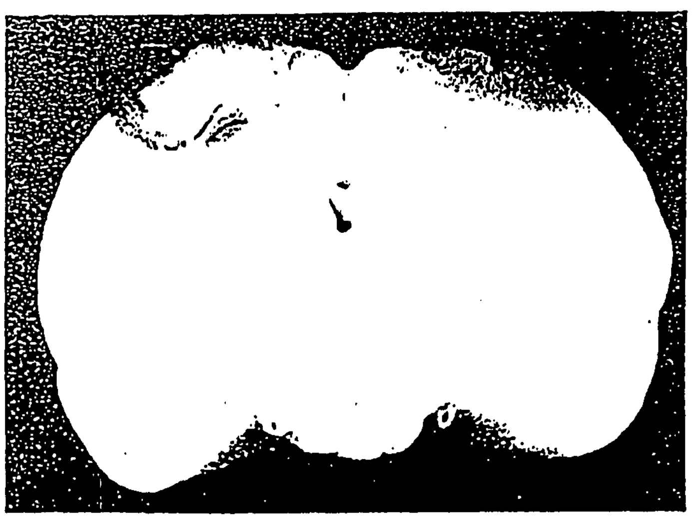

Fig. 15. On the *left* the deep necrosis caused by unipolar coagulation of surface vessels. On the *right* superficial change after bipolar coagulation of surface vessels

marked difference between the two is seen consistently (Fig. 15). Now if you set bo[th] unipolar and bipolar coagulators at the same power level you can blow the bra[in] apart on the bipolar treated side because so much less power is required for coagul[a]tion than with the unipolar connection because the return, i.e., the ground plate, [is] at a distance. So the coagulators must be matched to the lowest power for each t[o] coagulate for this to be meaningful.

The fact that we irrigate and do our coagulating under saline, since there is n[o] current spread, allows us to keep tissue cool. I have had my assistant irrigate with [a] simple bulb syringe of saline. In the laboratory many years ago, when I had no assi[s]tant, I used to keep a needle cemented to my bipolar forceps and run saline throug[h] it (Fig. 16). We are going back to that again as progressive cost cutting leaves us wit[h]out an assistant much of the time so that we now have available a forceps with an i[r]rigating tube controlled to go on and off with the bipolar which makes the assistan[t] unnecessary.

Different forceps sizes are essential, as part of your surgical armamentarium. You do not attempt to coagulate a vascular malformation with a fine pointed tip o[r] you can indeed perforate it by getting too high a current density at the tip. You us[e] a rounded, flat, broader blade which will allow you to shrink and bring down a ves[]sel. The fine tip is superb for sealing a tiny branch of an artery which must be pre

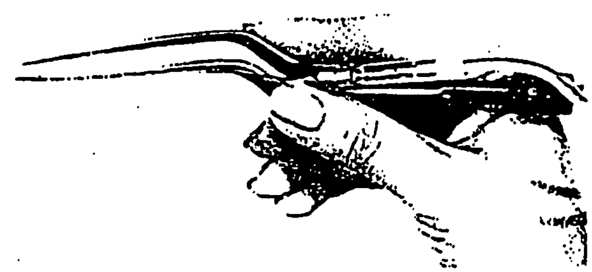

Fig. 16. Spinal needles cemented to side of bipolar forceps to provide irrigation

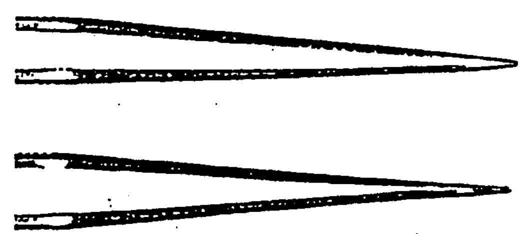

Fig. 17. Correct alignment of forceps blades in *upper half* of photograph, incorrect alignment with short circuiting proximal to the tips in the *lower* illustration

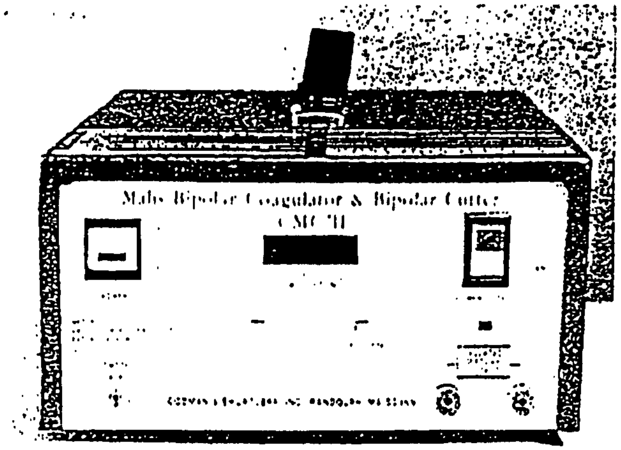

Fig. 18. The new solid state microprocessor controlled coagulator

Fig. 19. A right acoustic neuromas with the forceps tips applied to the capsule

served, for working against a tumor capsule or taking a minute vessel off the facial nerve without damaging the nerve.

It is essential that the forceps not touch each other as you work because if the forceps tips are in contact, the current just goes through the metal and coagulates nothing. Forceps may come through from the factories with the blades straight. When

Fig. 20. Same patient as Figure 19. The bipolar cutting current is being used to core the tumor

they pick up a vessel at the tip, they are shorted well back of the tip. The forceps blades should be concave enough to meet so that you can hold the vessel without shorting (Fig. 17). It is also essential that the surface be clean and polished. I polish them myself with an electrical hone between cases since I do not trust them any other way.

The spark generator puts out a completely asynchronous highly random damped series of spikes in each burst. In some commercial solid state coagulators, a damped sinewave is generated. Because it does resonate in part, it has higher cutting and higher bursting of vessels. It is rhythmic and resonant despite the fact that it is damped. We were finally able with the advent of microprocessor technology to program a microprocessor to change the height and width of each spike of the damped wave, to change the interspike interval and so the frequency of each spike separately thus producing an asyncronous, arrhythmic damped wave with solid-state equipment. This has an advantage in that it does not have the high first spike of the spark generator. It begins with a gentle start and so there is almost no sparking when you use it on the tissue. This is the basis of my new solid-state unit which I personally find has a tremendous advantage over the old spark gap device. This is purely the result of microprocessor technology (Fig. 18).

Additionally, the new solid state bipolar unit incorporates a pure sinusoidal wave form for use as a bipolar cutting instrument. This again is a low impedence, relatively low voltage technique. It cuts by molecular resonance without the high voltage arc to the tissue. As such it works only under saline irrigation. It is effective and efficient for coring tumors but not so good for dividing avascular fibrous tissue. I now use the cutting mode in virtually all neoplasm surgery (Figs. 19, 20, 21). It does indeed decrease for me the difficulty and duration of the surgical procedures.

Fig. 21. Same patient as in Figs. 19 and 20. A large segment of the tumor has been removed bloodlessy with the bipolar cutting current

Finally, I have mentioned several times the problem with engineers and surgical instruments. Bovie brought to Cushing one day a pistol-grip with a trigger and a Bovie ball on the end of it and suggested that Cushing coagulate with it instead of the little pencil instrument and the foot switch. Cushing looked at it and commented that it was very nice, and suggested that Bovie go and put a pencil in the muzzle of a pistol and write his name with it, and then he would see why surgeons rather than engineers should design surgical equipment.

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